NSF I/UCRC: Manufacturing & Materials Joining Innovation Center

# Computational Process Modeling for Additive Manufacturing

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## Background

Powder-Bed Additive Manufacturing (AM) through Direct Metal Laser Sintering (DMLS) or Selective Laser Melting (SLM) is being used by NASA and the aerospace industry to "print" parts that traditionally are very complex, high cost, or long schedule lead items. The process spreads a thin layer of metal powder over a build platform, then melts the powder in a series of welds in a desired shape. The next layer of powder is applied, and the process is repeated until layer-by-layer, a very complex part can be built. This reduces cost and schedule by eliminating very complex tooling and processes traditionally used in aerospace component manufacturing.

NASA MSFC AM Lab, printed components and SLM Printer

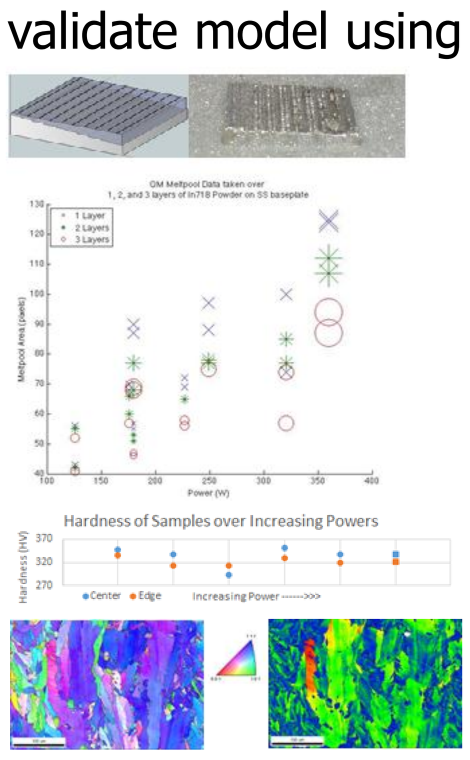
To use the process to print end-use items, NASA seeks to understand SLM material well enough to develop a method of qualifying parts for space flight operation. Traditionally, a new material process takes many years and high investment to generate statistical databases and experiential knowledge, but computational modeling can truncate the schedule and cost - many experiments can be run quickly in a model, which would take years and a high material cost to run empirically. This project seeks to optimize material build parameters with reduced time and cost through modeling.

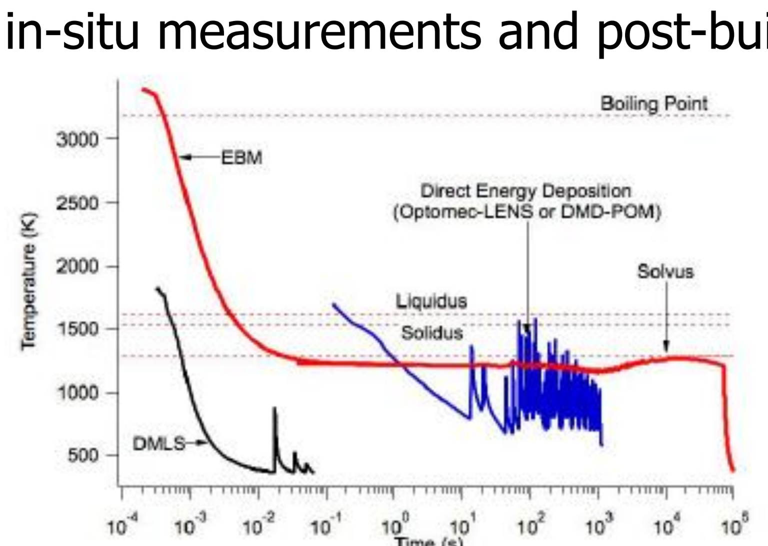
## Motivation

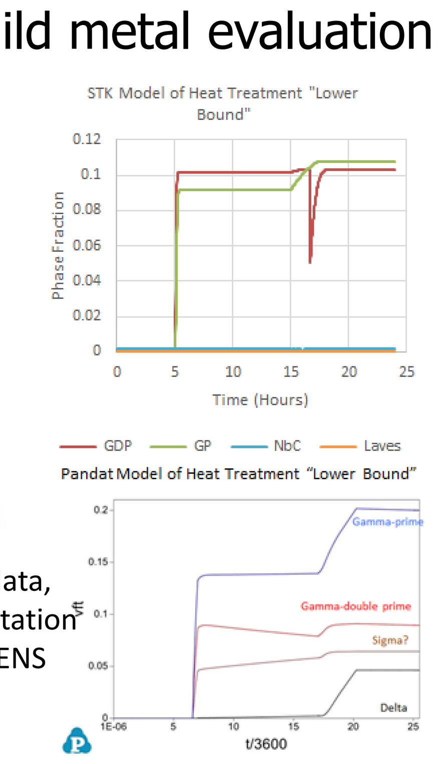
- •Model SLM process and microstructure evolution of IN718
  - •Optimize material build parameters with reduced time and cost
- •Increase understanding of build properties & reliability of builds
- •Decrease time to adoption of process for critical hardware
- •Potential to decrease post-build heat treatments

## Objectives & Approach

**Overarching Goal**: Model SLM process and resulting material; calibrate and validate model using in-situ measurements and post-build metal evaluation.





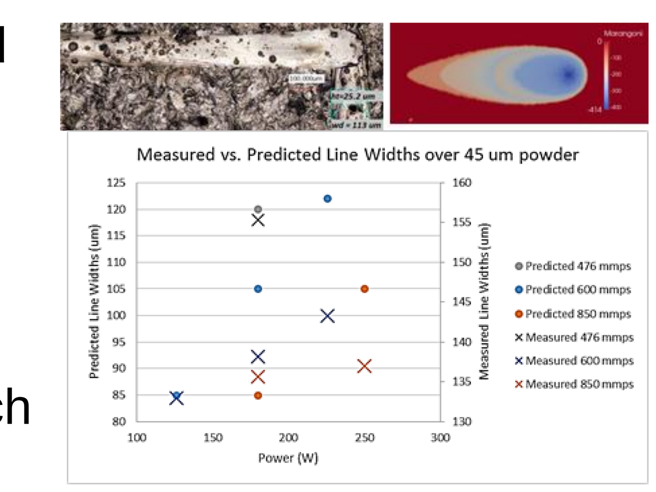



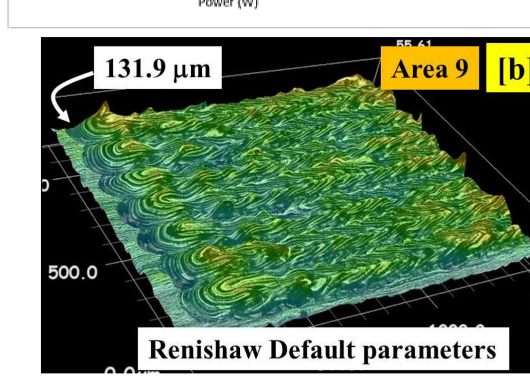
From Left to Right: Single track results and QM Meltpool data, hardness results (increasing power), Sample IPF and Orientation maps, AO Thermal History Prediction of EBM, DMLS and LENS process, and GRC Prediction of Heat Treatment effect on precipitations (C. Sudbrack) compared with STK model.

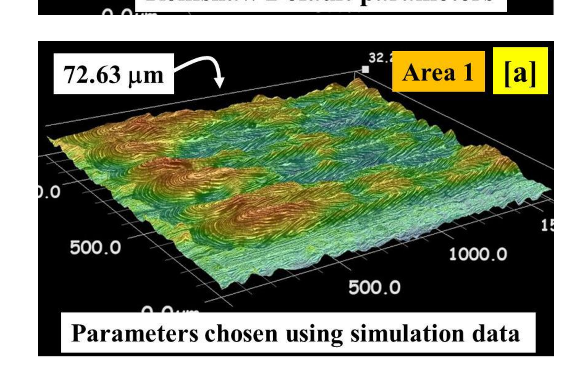
- •Conduct single-track and coupon builds at various build parameters
- •Record build parameter information and QM Meltpool data
- •Refine Applied Optimization powder bed AM process model using data
- •Report thermal modeling results
- •Conduct metallography of build samples
- •Calibrate STK models using metallography findings
- •Run STK models using AO thermal profiles and report STK modeling results

## Results & Discussion

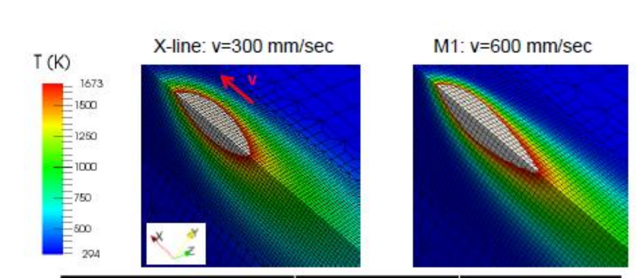
- •Single-tracks & coupons were printed & related to weld models from Applied Optimization
- •AO continues to work with NASA to model the SLM Process through a STTR.
  - •Focus on weld bead shapes to minimize porosity & defects
  - •The weld dimensions affect each layer, which affects the total stack-up and build quality.
- •AO has also modeled the thermal history of a point in SLM (DMLS) and shown the curve to be orders of magnitude different than LENS or EBM systems (see "Objectives" for this graph). In this scenario, printing an aged material is difficult and all SLM718 will need to be heat treated.
- •STK modeling of the as-built condition will be uninformative for SLM718, but models may lead to optimized heat treatment schedules.



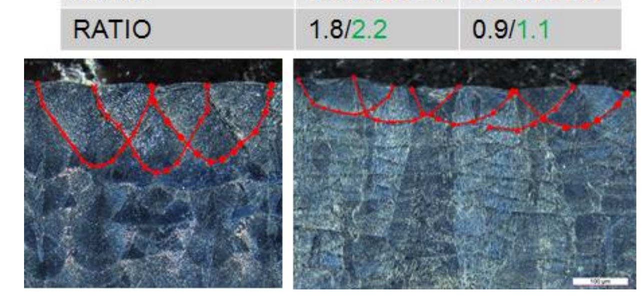




Above: AO Predictions and Results




| PREDICTED/ACTUAL | DEPTH (mm) | WIDTH (mm) |
|---|---|---|
| M1 | 0.034/0.152 | 0.108/0.209 |
| XLINE | 0.019/0.065 | 0.119/0.188 |
| RATIO | 1.8/2.2 | 0.9/1.1 |



- •AO, NASA Langley, and others are conducting weld models to predict shape of the weld pool with incident laser parameters.
- •This has been useful in determining parameters such as hatch spacing and layer thickness, and in providing a basis on which to estimate parameters when moving across platforms (such as using a different laser power or shape).

## Conclusions

### Challenges

This project intended to leverage previously-developed models, not develop a modeling capability. The SLM process is too significantly different to leverage LENS models, and the STK model needs further development for use on SLM of IN718.

Due to complex physics for SLM, models are evolving and not yet turnkey solutions. However, they have helped advance the understanding of SLM process and microstructure, as shown below.

### Opportunities

Other models may become useful for the process, such as grain-growth based on weld pool shape, or phase evolution based on heat treatment. Modeling is also being used for problem solving or root cause determination in order to understand the effects of various parameters or heat treatments, as well as to develop cross-platform equivalent parameter sets.

## Future Work

This project has generated interest at NASA in modeling the SLM/DMLS process and applications of process and materials models:

- •MSFC became involved in the NASA Materials Genome Initiative, where:
  - •MSFC developed a thermal model and proposed solidification modeling
  - •GRC modeled microstructure evolution during heat treatment
  - •ARC modeled laser interaction with powder particles
  - •LaRC developed a weld-pool model
- •NASA Sponsored 3 STTR phase I and II in Additive Manufacturing modeling
- •MSFC is collaborating with the Additive Manufacturing Consortium and the University of Louisville for AM Process Modeling efforts
- •MSFC helped develop the proposal for University of Tennessee to join the CIMJSEA/MaJIC and will sponsor a UTK project on Additive Manufacturing

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